To: Mr. Chas. J. McCarthy

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THE EFFECT OF SURFACE IRREGULARITIES ON WING DRAG

II - LAP JOINTS

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SUMMARY

Tests have been made in the N.A.C.A. 8-foot high-speed wind tunnel of the drag caused by four types of lap joint. The tests were made on an airfoil of N.A.C.A. 23012 section and 5-foot chord and covered a range of speeds from 80 to 500 miles per hour and lift coefficients from 0 to 0.30.

The increases in profile drag caused by representative arrangements of laps varied from 4 to 9 percent. When there were protruding rivet heads on the surface, the addition of laps increased the drag only slightly. Laps on the forward part of a wing increased the drag considerably more than those farther back.

INTRODUCTION

Skin-friction drag is a major portion of the total drag of well-streamlined present-day airplanes. It is therefore important that skin friction be reduced as much as possible. It has been shown that rivet heads (reference 1), certain arbitrary protuberances (references 2 and 3), and surface roughness (references 4 and 5) greatly increase the drag of wings. A recent series of tests by the N.A.C.A. has shown the effects on wing drag of a wider range of rivet sizes, types, and arrangements and of spot welds (reference 6), of several degrees of surface roughness (reference 7), and of manufacturing discrepancies (reference 8).

The present paper gives the results of tests made in the N.A.C.A. 8-foot high-speed wind tunnel to determine the effect on wing drag of the surface discontinuities resulting from lapped joints in sheet-metal construction. The types of lap joints tested included: joggled laps facing aft, plain laps facing aft both with and without rivets, plain laps facing forward, and faired laps facing forward.

The results of the tests showed the increase in the drag of an airfoil of N.A.C.A. 23012 profile and 5-foot chord caused by typical arrangements of each type of lap and the drag reduction obtained by eliminating one or more of the forward laps. The tests were made at lift coefficients from 0 to 0.30 and at speeds from 80 to 500 miles per hour, corresponding to Reynolds Numbers from 3,000,000 to 18,500,000.

APPARATUS

The tests were conducted in the N.A.C.A. 8-foot high-speed wind tunnel. The air flow in the closed circular test section of this wind tunnel is quite uniform and the turbulence of the air flow is so small that sphere tests have shown virtually the same critical Reynolds Number in the tunnel as in free air (reference 9).

An N.A.C.A. 23012 airfoil having a chord of 5 feet and an active span of 6 feet was used for these tests. Figure 1 shows the airfoil mounted in the wind tunnel. A description of the airfoil and its arrangement in the tunnel is given in reference 6. The lap joints were simulated by cuts made in the surface of the airfoil to represent lapped sheets 0.018 inch thick but actual 3/32-inch brazier-head rivets, with the shanks pressed into holes in the airfoil, were used for the tests to determine the combined effect of rivets and laps (fig. 2). The chord positions of the laps and rivets are shown in figure 3. The rivets were at 3/4-inch pitch in spanwise rows at the chord positions shown. The rivet holes were plugged and finished flush when not in use. Aside from the laps and rivets, the airfoil surface was aerodynamically smooth; that is, further polishing would bring about no measurable reduction in drag.

METHOD

The lift, the drag, and the pitching moment of the airfoil with each arrangement of laps, or of laps and rivets, were determined at -1.25°, -0.15°, and 0.95° angle of attack, corresponding to lift coefficients of approximately 0, 0.15, and 0.30, respectively. The tests at lift coefficients of 0.15 and 0.30 were made at speeds varying from 80 to 370 and from 80 to 270 miles per hour, respectively, the upper limit in each case producing a

wing loading of approximately 50 pounds per square foot. For the tests at zero lift, the speed was varied from 80 miles per hour to a speed at which the drag coefficient began to increase rapidly due to compressibility effects, about 500 miles per hour under the conditions of these tests.

The order of testing was, briefly, as follows: The joggled-lap simulations were cut in the airfoil starting with the three rear laps in each surface and were added one at a time as the tests proceeded. After all the joggled laps had been cut and tested, they were widened to simulate plain laps facing aft. The airfoil was tested in this condition; 13 rows of rivets were then added on each surface, and further tests were made. The rivets were removed, the rivet holes plugged, finished flush and smooth, and the airfoil again tested. The laps were then filled, one or more laps at a time, starting at the front and proceeding rearward, and tests were made after each change. After all these laps were filled, the simulations of plain laps facing forward were cut in the surface starting with the three rear laps and working forward one or more laps at a time as tests proceeded until all these laps had been cut and their effects determined. The final step was to round the corners of the plain laps facing forward to produce the simulations of faired laps facing forward and to measure the drag for this condition. The drag of the smooth airfoil without laps was measured before and after and once during these tests.

At the high speeds attained in the N.A.C.A. 8-foot high-speed wind tunnel, the dynamic pressure $(q = \frac{1}{2} \rho V^2)$ used in computing force and moment coefficients departs considerably from the impact pressure shown by a pitot-static tube. The method by which the dynamic pressure, air speed, and Reynolds Number in the test section are computed is presented in reference 6.

RESULTS

The tunnel effects on the characteristics of an airfoil that is as large relative to the tunnel diameter as the one used in these tests are quite appreciable. Since these effects have not yet been completely determined for this wind tunnel, no corrections have been applied and none of the results are presented as absolute drag coeffi-

cients. The results are, instead, presented in terms of increases in drag coefficient, which should be little altered by tunnel effects.

Even though the drag results should usually be applied on the basis of Reynolds Number, they are, for expediency, shown in terms of Mach number M, (the ratio of the air speed to the speed of sound in the air) because, at the higher speeds employed in the tests, compressibility effects cause drag coefficients to vary so rapidly with M that comparisons are preferably made at equal values of this parameter. The air speeds given are not actual test air speeds at the reduced densities existing in the wind tunnel but are speeds which, at sea level in standard atmosphere, would produce values of M equal to the test values. The Reynolds Numbers are the averages of the actual Reynolds Numbers for the various test runs. None of the Reynolds Numbers departs from these averages enough to affect the results appreciably.

Increases in the drag of the airfoil caused by six laps on each surface are plotted against M in figure 4 for each of the four types of lap tested and for plain laps facing aft in combination with 13 rows of 3/32-inch brazier-head rivets on each surface. Curves from reference 6 showing drag increases caused by 3/32-inch brazier-head rivets in the absence of laps are included for comparison. In order to aid in visualizing the magnitude of the drag increases, the approximate percentage increases at one Reynolds Number, using as base values full-scale wind-tunnel results from reference 10 corrected for tip effects, are shown for a few representative points.

As laps were eliminated starting with the forward pair (one on each surface), the lap drag decreased as shown in figure 5. This figure shows data for a tunnel speed of 230 miles per hour and for a lift coefficient of 0.15. Similar results were found for other speeds and lift coefficients. The effects of laps on the upper and lower surfaces of the airfoil were not separated.

None of the conditions tested had any appreciable effect on lift or pitching moment at any of the angles of attack included in the tests, which covered the usual high-speed and cruising range.

PRECISION

Only increases in drag coefficient are reported herein. For the reasons discussed in reference 6, random errors in these increases probably do not exceed ± 0.0001, corresponding to ± 1.4 percent of the drag of the smooth airfoil, except at speeds below 100 and above 400 miles per hour, where the errors may be twice this value. Systematic errors are thought to be small enough that their effect on the results is not important.

DISCUSSION

The relative merits of the four different types of lap can be judged from figure 4. The joggled laps were the best type tested. Plain laps facing forward caused the greatest increase in drag but, when these laps were faired by rounding the edges of the sheets, the drag was about the same as that of the more commonly used plain laps facing aft.

The drag caused by laps was small compared with the drag caused by protruding rivet heads. For example, plain laps facing aft increased the drag only about one-third as much as 3/32-inch brazier-head rivets. The drag increases caused by laps were of the same order of magnitude as the increases caused by countersunk rivets (reference 6).

From the results shown in figure 4 it can be seen that the effects of rivets and laps are not additive. Adding plain laps facing aft to a wing already having 3/32-inch brazier-head rivets increased the drag only about one-third as much as adding the same laps to an otherwise smooth wing.

The drag caused by lap joints increased as Reynolds Number was increased up to about 12,000,000 (fig. 4). As Reynolds Number was further increased, the lap drag decreased but this decrease cannot be attributed entirely to scale effect because the test speeds corresponding to the higher Reynolds Numbers were so high that compressibility effects might have been predominant. From the nature of the scale effect, it is evident that small-scale tests of lap drag are unreliable.

Figure 5 shows that, as laps were eliminated starting

with the forward laps, the drag was reduced quite rapidly at first but that the reduction became approximately linear 25 percent of the chord back from the leading edge. This reduction of lap drag was similar to the reduction shown for rivets in reference 6 and re-emphasizes the importance of keeping the forward portions of wings smooth.

Inasmuch as lap simulations representing only one sheet thickness, 0.018 inch (0.030 percent chord), were tested, no data are provided on the variation of lap drag with sheet thickness. It must be remembered that, as in the case of rivets (reference 6), the dimensions and arrangements of lap joints must be considered in terms of wing chord.

The effect on the performance of an airplane having the following assumed characteristics will be considered to illustrate the importance of the drag caused by laps on an airplane wing:

Gross weight - - - - - - - - - -	25,000 pounds.
Wing area - - - - - - - - - - - -	1,000 square feet.
Wing span - - - - - - - - - - - -	100 feet.
Cruising speed - - - - - - - -	200 miles per hour.
Cruising altitude - - - - - - -	8,000 feet.
Cruising power - - - - - - - -	1,200 horsepower.
Propeller efficiency - - - - - -	85 percent.
Type of lap on wing surface -	Plain laps facing aft.
Thickness of lapped sheets - -	0.036 inch (0.030 percent chord).
Position of forward laps - -	8 percent chord.
Number of laps - - - - - - - - -	6 on each surface.

Wing otherwise smooth.

From these assumed characteristics the following can be computdd:

Average chord - - - - - - - - - 10 feet.

Cruising Reynolds Number - - - 14,400,000

Cruising C_D - - - - - - - - - 0.0238

Cruising C_L - - - - - - - - - - 0.31

From figure 4, it is seen that eliminating the laps from the wing of this airplane would reduce the drag coefficient by about 0.0004. With this drag reduction the airplane would cruise at 201.3 miles per hour with the same power as before, or the original cruising speed of 200 miles per hour could be maintained with 20 horsepower less.

Kendall Perkins (reference 11) has estimated that increasing the speed of a 25,000-pound transport airplane 1 mile per hour increases its sales value approximately $1,000. If this estimate be accepted, approximately $1,300 per airplane could be economically expended in eliminating the laps from the wing. The gains would be larger for airplanes cleaner than the one assumed.

CONCLUSIONS

The most important conclusions drawn from the tests can be summarized as follows:

1. Lapped joints in a representative arrangement increased the profile drag from 4 to 9 percent.

2. As laps were eliminated starting with the forward laps, the drag was reduced quite rapidly at first but the reduction became approximately linear 25 percent of the chord back from the leading edge.

3. With a typical arrangement of brazier-head rivets on a wing, the additional drag due to laps was small.

Langley Memorial Aeronautical Laboratory,
National Advisory Committee for Aeronautics,
Langley Field, Va., December 2, 1937.

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FIGURE LEGENDS

Figure 1.- Airfoil with 3/32-inch brazier-head rivets and plain laps facing aft mounted in wind tunnel. The airfoil is set at a large negative angle to show the laps and rivets.

Figure 2.- Details of simulations of laps. All dimensions are in inches.

Figure 3.- Positions of laps and rows of rivets used in tests.

Figure 4.- Increase in drag due to six laps on each surface of airfoil.

Figure 5.- Drag due to laps with forward laps at various chord positions: C_L, 0.15; V, 230 m.p.h.; average R, 10,200,000.

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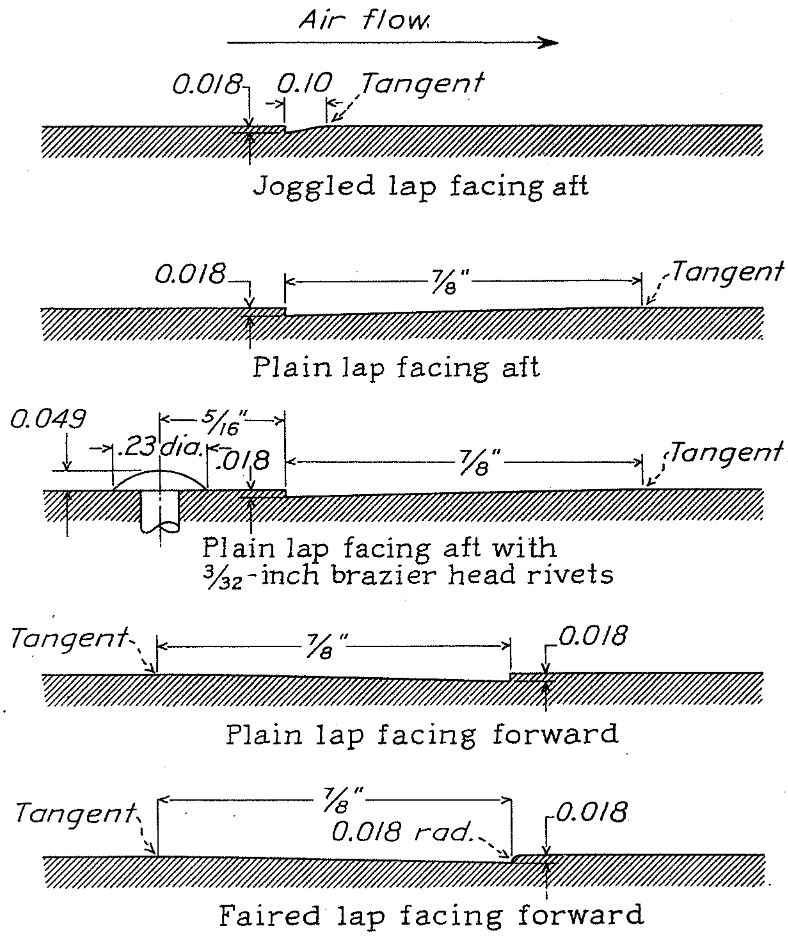

Figure 2

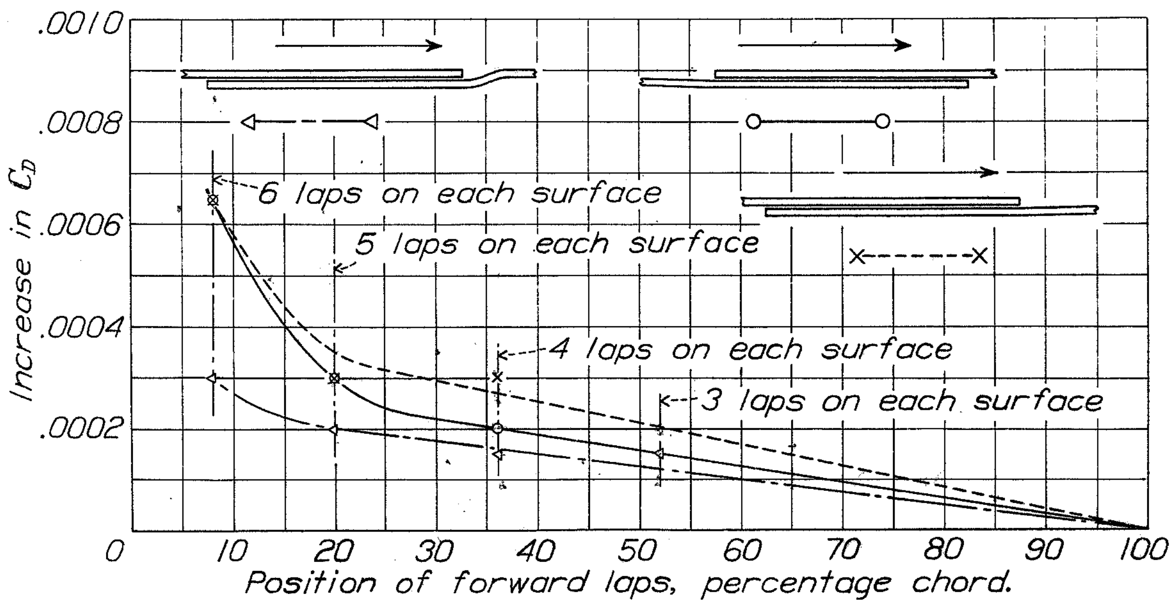

Figure 5

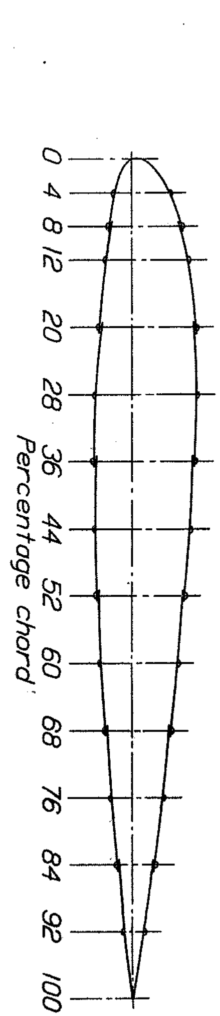

Figure 3

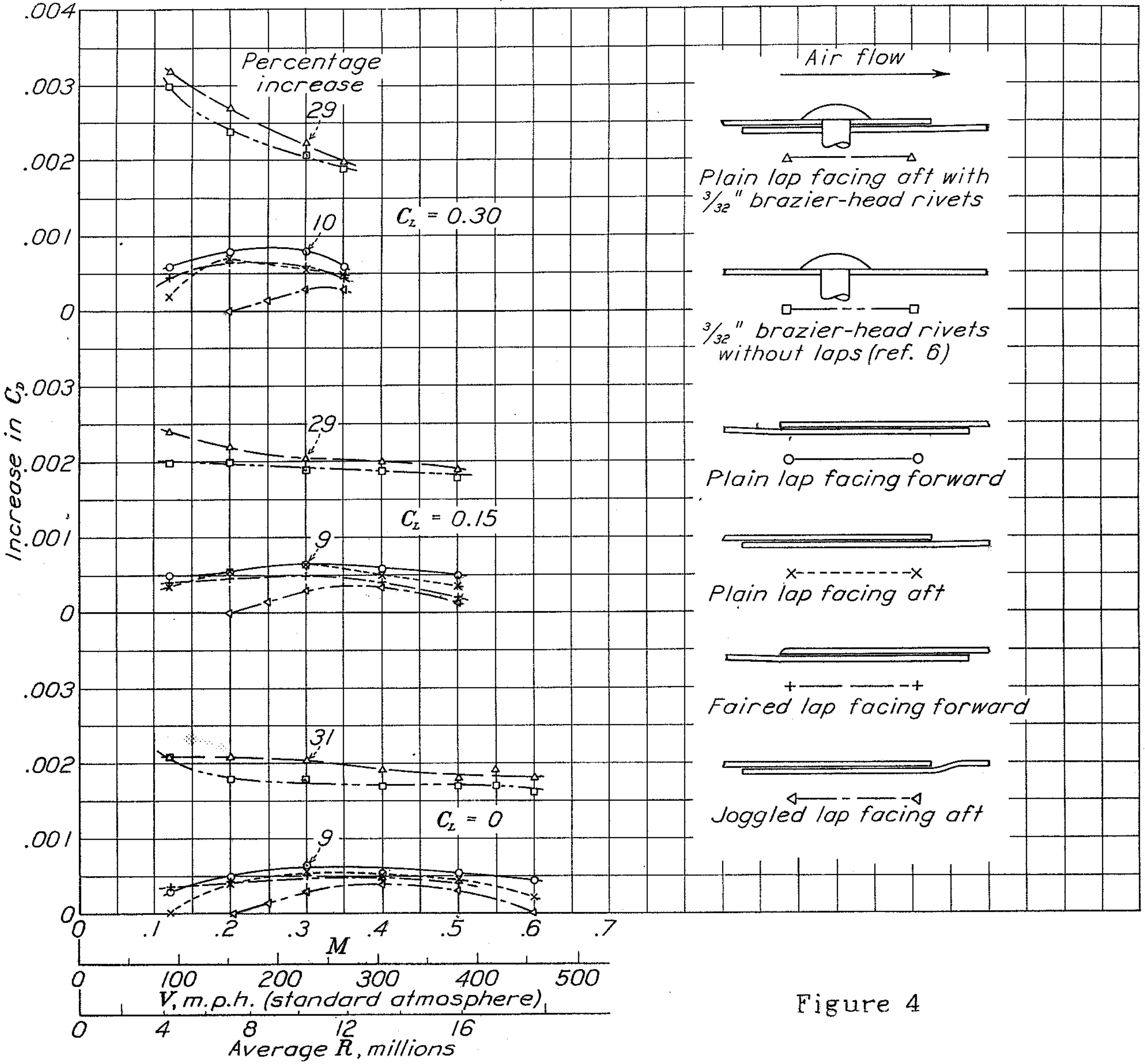

Figure 4